



#### Potential Case of Induced Seismicity from a Water Disposal Well in South-Central Oklahoma

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Powell Center – Injection Induced Seismicity Working Group

# Damage summary from the magnitude 3.4, Sep. 23, 2013

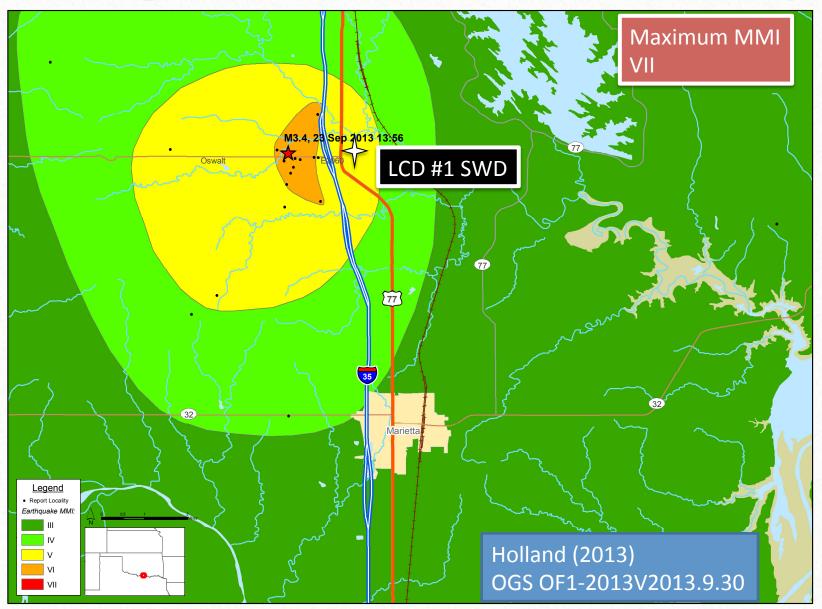
#### **Damage to Homes**

- Collapsed Chimney (1)
- Shattered Window (1)
- Damaged brick façade (~5)
- Doors and frames crooked (~5)
- Cracked foundations
  - Difficult to distinguish from normal OK soil effects
- Cracked drywall and cosmetic damage (~15-20)
- Fallen objects and strong shaking (>20)

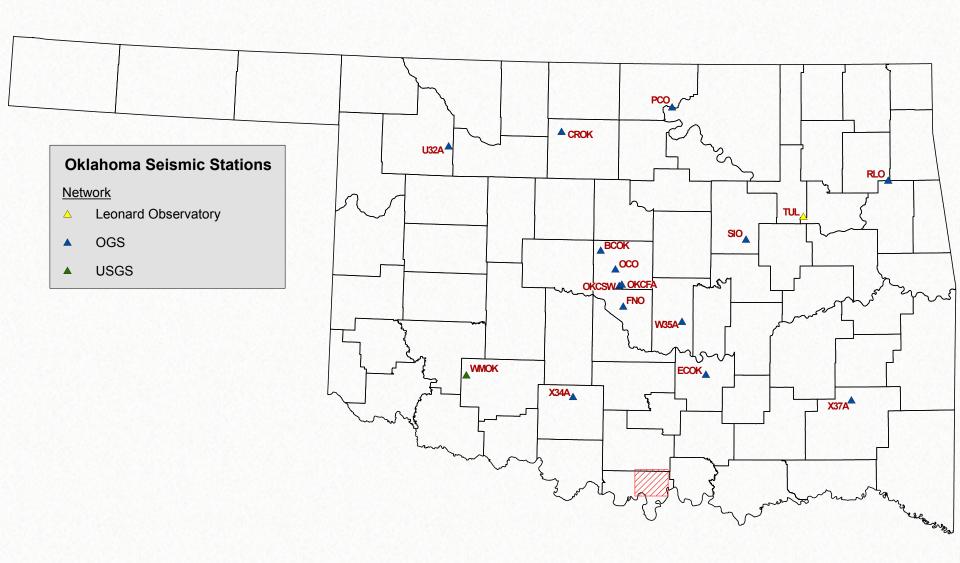


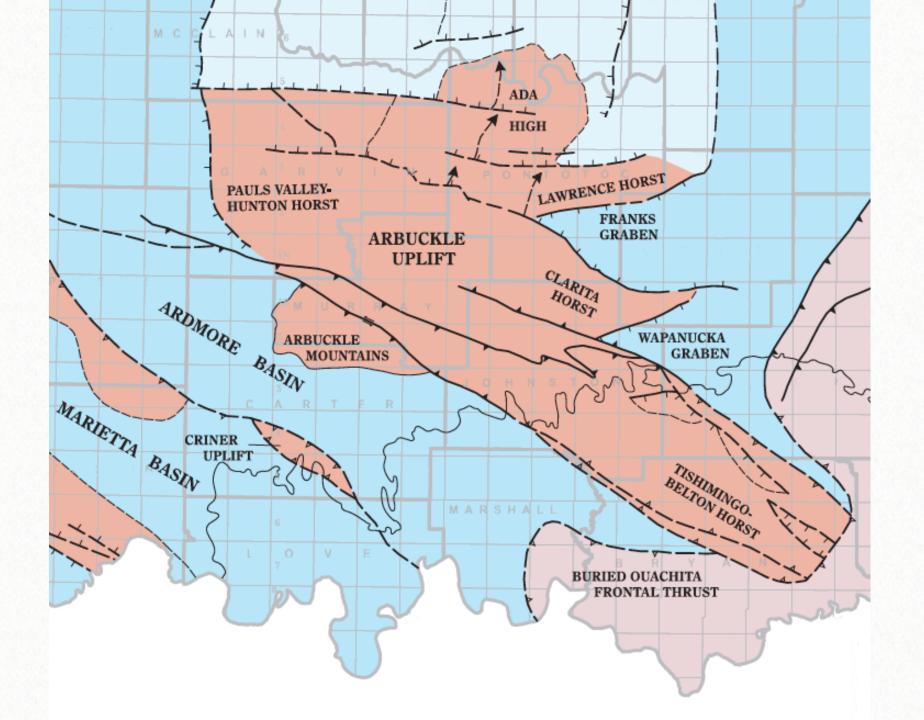
**Photo courtesy of Rhonda Lumry** 

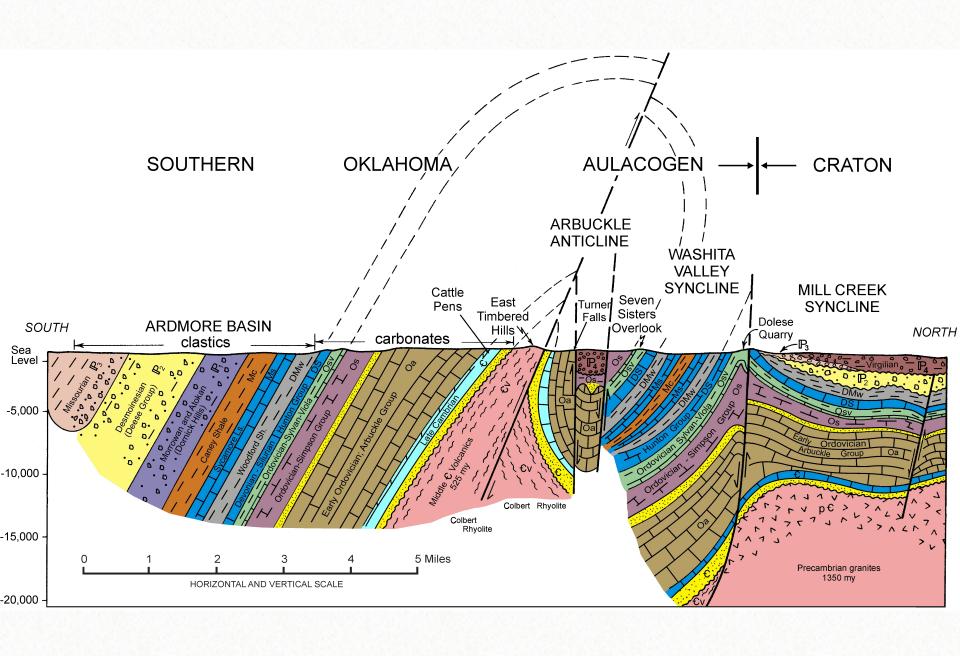
#### Felt Reports to Modified Mercalli Intensity

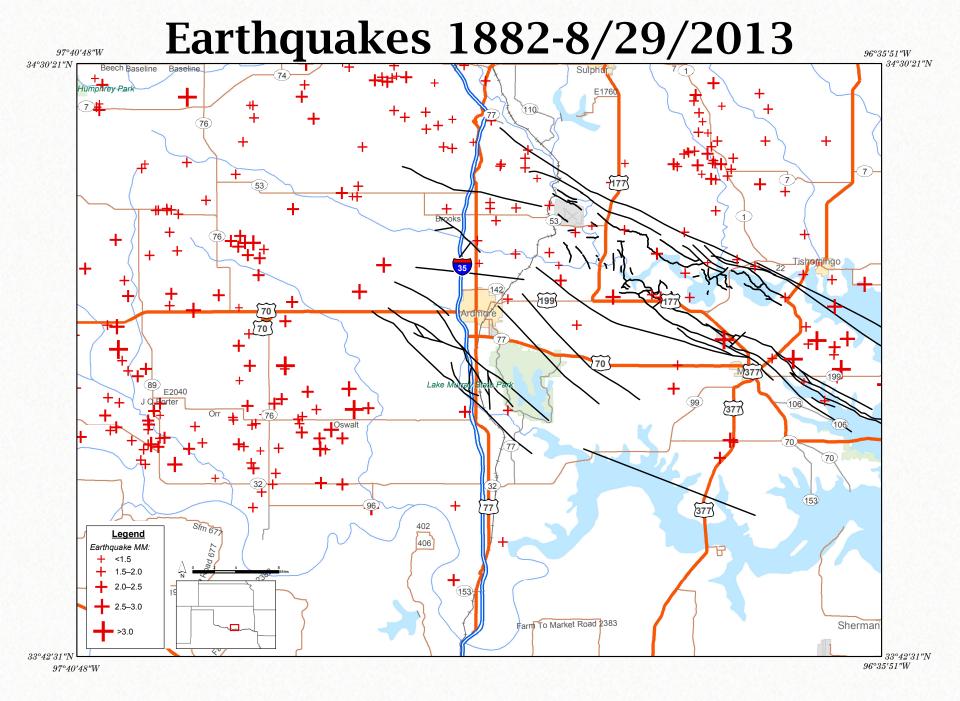


## **Regional Seismic Stations**



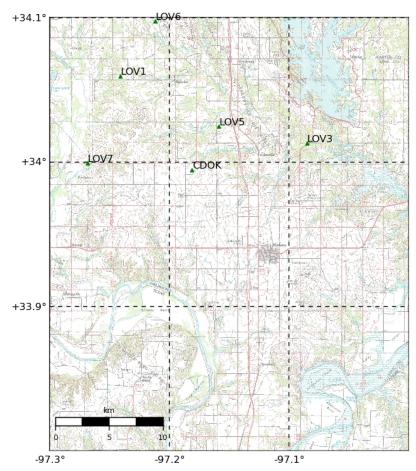




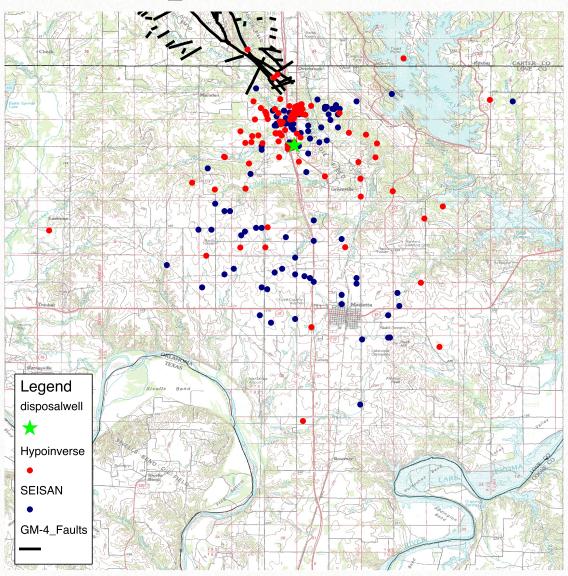


### **Temporary Network**

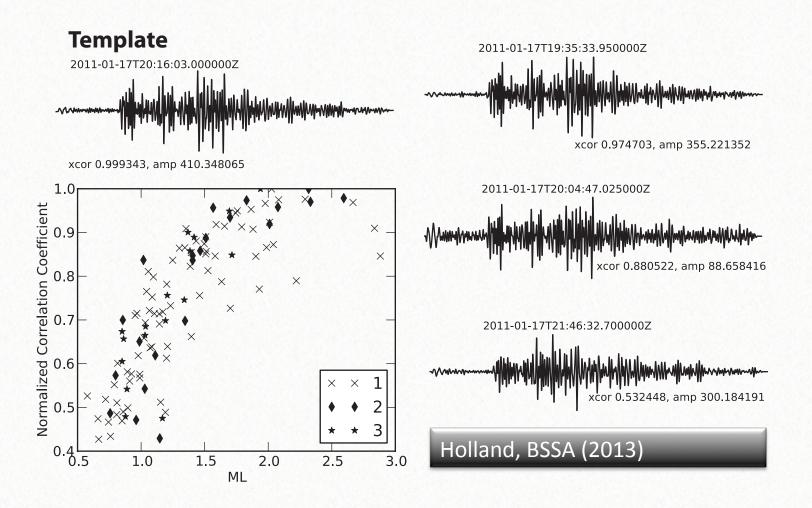
- First station installed 9/26
- Currently operating 6 stations in the area
- 2 stations have been moved due to logistics reasons
- Detection threshold about M 0.0 within the area
- Status is continuously reported
  - http://wichita.ogs.ou.edu/ eq/love/stations/



## **Earthquake Locations**

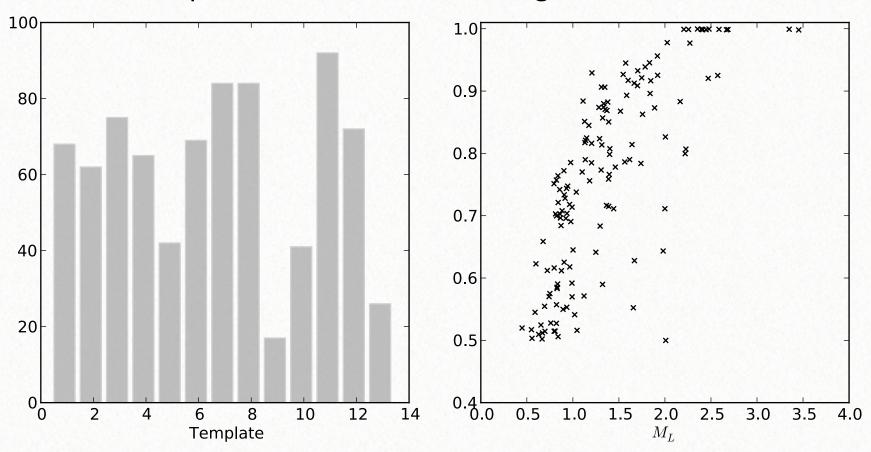


#### **Example Waveform Cross Correlations**

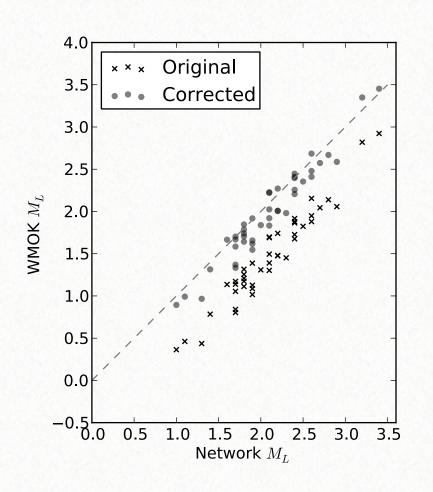


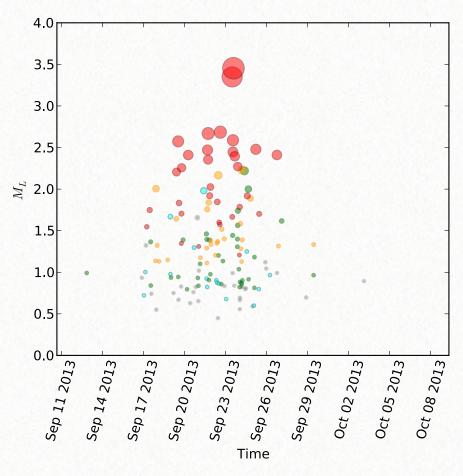
#### **Cross-Correlations for Love County**

142 Unique Events Identified through cross-correlation

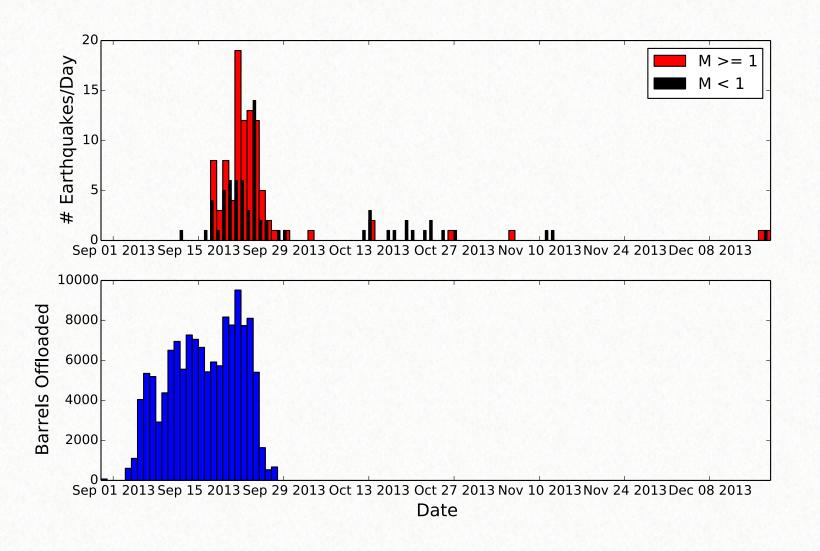


# Magnitude Calculations for Love County





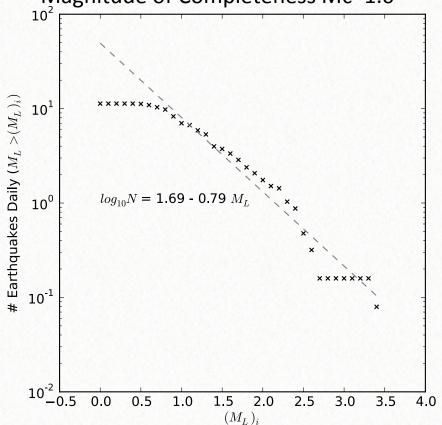
#### LCD #1 Injection and Earthquakes



#### Recurrence and b-values

#### **WMOK Cross Correlations**

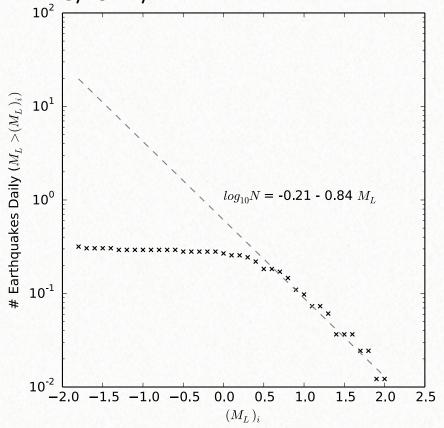
Events from 9/16 to 9/29 Magnitude of Completeness Mc~1.0



Predicts about 50 magnitude 0 earthquakes daily

#### **Earthquakes located using local network**

Mc~0.3 9/29-12/17



Predicts about 1 magnitude 0 earthquake every other day

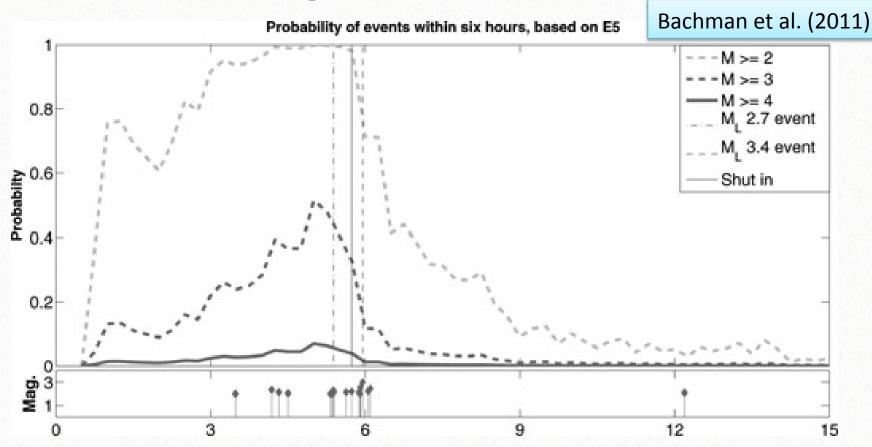
## Why allow injection at LCD #1

- Cannot definitively state that the earthquakes were directly caused by injection at LCD #1
  - The earthquakes are similar in characteristic to past swarms in the area and could simply be an unlikely coincidence
- Damage estimates from M3.4 are much less than the cost of a disposal well
- We are developing a system that would minimize risk and allow the operator to potentially continue operating and recover cost of the well
  - Cannot predict earthquakes and there is some risk in allowing injection to resume
- If the earthquakes can be shown to clearly be caused by injection at LCD #1, then proper damage claims could be assessed

#### **Path Forward**

- Establish a set of criteria to allow injection to resume at the yellow light with initial injection starting at the current level for some period of time
  - If all earthquake criteria are met for some period of time not yet identified (~14 days)
  - Injection is allowed to increase to two pumps ~3,000 bbls/day and will be held at this level for some amount of time
  - If all is still fine injection would be allowed to increase to full scale, but under the yellow light condition
    - Earthquake monitoring continues and a red light could occur if any of the earthquake conditions are met.

#### Probability based monitoring



Past earthquakes even small can help determine the likelihood of exceeding some threshold "real-time" traffic light system.

# Proposed earthquake criteria for Red Light on injection

- Still working out the details, but these are our general thoughts at present
- If any one of these criteria is met a red light on injection occurs
- If a magnitude 1.8 (M threshold), occurs this is the magnitude, which people are feeling earthquakes
  - If it is a foreshock to a larger earthquake generally a mainshock is ~ 1 magnitude unit greater (Still below the damage threshold)

# Proposed earthquake criteria for Red Light on injection (continued)

- If the rate of earthquakes increases after injection begins such that we can say at the 99% confidence interval that the earthquake rate is distinct from the background rate currently being monitored
- If we reach the point in the Gutenberg-Richter law where we have a 95% or greater chance of the next earthquake exceeding magnitude (M threshold)

#### **Abstract**

On September 17, 2013, a swarm of earthquakes began in Love County, Oklahoma, north of Marietta. These earthquakes began occurring about two weeks after injection began at a nearby disposal well. The largest earthquake was a magnitude 3.4, which did minor damage to structures in the epicentral area and had a maximum Modified Mercalli Intensity of VII. Local residents consistently feel magnitude 1.8 earthquakes. The earthquakes are occurring at shallow depths consistent with injection depths of the nearby disposal well. The sequence included 22 earthquakes of magnitude 2.0 or greater with more than 100 earthquakes identified during the period which injection occurred. Regional seismic stations provide poor coverage of the earthquakes, in part due to the shallow focal depths. A temporary network of six seismic stations was deployed in the area. This network greatly enhanced earthquake locations and dramatically improved the magnitude of completeness. Earthquakes continued after injection ceased but at a lower frequency and smaller magnitudes with only one felt earthquake. This area has seen similar shallow earthquake swarms in the past. It is important to address whether or not this swarm of earthquakes is caused by fluid injection at the nearby disposal or simply an unlikely coincidence. Techniques used to improve event identification and locations of the earthquakes are presented. A statistical method to quantitatively address seismicity changes is adopted and implemented in a monitoring system, in the event injection resumes in the disposal well or in a nearby well that was recently completed. The operator of the disposal well is currently restricted on injection rates and volumes, but may continue injection under the yellow light condition placed on injection by the Oklahoma Corporation Commission. However, the operator has not currently chosen to inject under these restrictions, if injection resumes the results of the statistical monitoring and traffic light system will be presented.